JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
VOL. 38, NO. 4 AMERICAN WATER RESOURCES ASSOCIATION AUGUST 2002

IMPACTS OF URBAN LANDUSE ON MACROINVERTEBRATE COMMUNITIES IN SOUTHEASTERN WISCONSIN STREAMS[1]

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ABSTRACT: Macroinvertebrates were used to assess the impact of urbanization on stream quality across a gradient of watershed imperviousness in 43 southeastern Wisconsin streams. The percentage of watershed connected imperviousness was chosen as the urbanization indicator to examine impact of urban land uses on macroinvertebrate communities. Most urban land uses were negatively correlated with the Shannon diversity index, percent of pollution intolerant Ephemeroptera, Plecoptera, and Trichoptera individuals, and generic richness. Nonurban land uses were positively correlated with these same metrics. The Hilsenhoff biotic index indicated that stream quality declined with increased urbanization. Functional feeding group metrics varied across a gradient of urbanization, suggesting changes in stream quality. Proportions of collectors and gatherers increased, while proportions of filterers, scrapers, and shredders decreased with increased watershed imperviousness. This study demonstrated that urbanization severely degraded stream macroinvertebrate communities, hence stream quality. Good stream quality existed where imperviousness was less than 8 percent, but less favorable assessments were inevitable where imperviousness exceeded 12 to 20 percent. Levels of imperviousness between 8 and 12 percent represented a threshold where minor increases in urbanization were associated with sharp declines in stream quality.
(KEY TERMS: aquatic ecosystems; nonpoint source pollution; urban landuse; imperviousness; urban runoff; stream quality; macroinvertebrates; biotic index; functional feeding groups.)

INTRODUCTION

Urbanization frequently degrades aquatic ecosystems. Nonpoint source pollutants such as heavy metals, oil, pesticides, road salts, organic materials, nutrients, and sediments have been attributed to water quality degradation in urban streams (Whipple and Hunter, 1979; Randall *et al.,* 1981; Lenat and Crawford, 1994; Rosenberry *et al.,* 1999). Additionally, with increased development, roads, buildings, and other surfaces that are impervious to stormwater infiltration replace vegetated and natural areas in the watershed. This process increases storm water runoff to streams, thereby increasing the frequency and severity of floods, and accelerating channel erosion (Booth and Jackson, 1997). Bed composition, stream morphology, and base flows are also affected (Klein, 1979; Wang *et al.,* 2001).

The alterations of stream water quality, hydrology, and channel morphology caused by urbanization have led to major changes in aquatic macroinvertebrate communities. By linking housing and population densities with percent of watershed development, studies have demonstrated that urbanization altered macroinvertebrate community composition and reduced macroinvertebrate community taxa richness, numbers of pollution intolerant taxa, diversity, and overall biological health (Benke *et al.,* 1981; Pitt and Bozeman, 1983; Pedersen and Perkins, 1986; Jones and Clark, 1987).

Recent advances in the availability of landuse databases and geographic information systems (GIS) have allowed a more systematic description of urbanization effects, as measured by the percent of watershed area that is impervious, on biologic communities. The amount of impervious surface in a watershed has been proposed as a key environmental indicator of urban land use effects (Schueler, 1994; Arnold and Gibbons, 1996). Watershed imperviousness has had an obvious direct effect on stream hydrology and quality, as well as an indirect influence on stream habitat

[1]Paper No. 00051 of the *Journal of the American Water Resources Association.* **Discussions are open until February 1, 2003.**
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and fish communities (Booth and Jackson, 1997; Wang *et al.,* 2000; Wang *et al.,* 2001). This factor is also one of the few urban landuse attributes that can be explicitly quantified and controlled at each stage of land development (Schueler, 1994). Therefore, models that link urbanization indicators, such as imperviousness, with stream quality measures, can be effective tools for watershed planners, developers, and managers to wisely use our natural resources. However, few studies have examined the effects of watershed landuse, particularly urban landuse, on macroinvertebrate communities in the Midwest (e.g., Richards *et al.,* 1996; Roth *et al.,* 1996; Lammert and Allen, 1999).

In the present study, we first compared relationships between major landuse variables and various macroinvertebrate community attributes to identify a key urban landuse indicator that had the strongest relation with macroinvertebrate communities and that could represent the other urban landuse variables. We then used the identified best landuse variable to examine relations between watershed urban landuse and macroinvertebrate community attributes to define, if possible, a threshold of watershed urbanization at which stream macroinvertebrate community quality experienced dramatic change, and beyond which macroinvertebrate community quality was consistently poor.

METHODS

Study Area

We studied watershed land use and macroinvertebrate assemblages at 43 stream sites, the same locations where impacts of urbanization on fish communities were evaluated (Wang *et al.,* 2000; Wang *et al.,* 2001) in southeastern Wisconsin (Figure 1). All streams were located in unique subwatersheds within the Southeastern Wisconsin Till Plains Ecoregion (Omernik and Gallant, 1988). Most of this area has low relief and slopes are predominantly level to slightly rolling. The stream drainage system is poorly developed and undrained depressions are common. Wang *et al.,* (2000) provided a detailed description of each study stream. Due to the nutrient rich soils and low relief, this ecoregion was historically an important agricultural area, but by 1990 about two million people lived in this region, and agricultural landuse had decreased.

Three criteria were used to select the study sites. First, sites with historical fish population data were selected to meet requirements of a concurrent study that examined the effects of urbanization on fish communities (Wang *et al.,* 2000; Wang *et al.,* 2001). Next, sites were chosen in watersheds for which detailed land use data could be obtained. Finally, to minimize natural variation in biotic communities, sites with similar watershed soil types, stream size and slope, and natural hydrological and temperature regimes were selected. Study sites represented a wide range of urban development and environmental quality, from least impacted regional reference conditions to heavily degraded conditions.

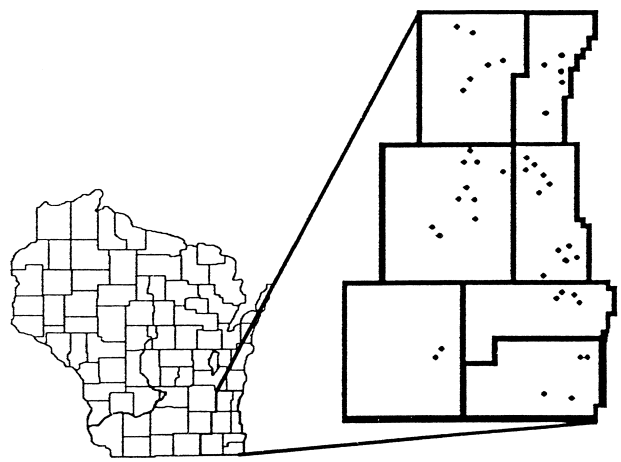

Figure 1. Forty-Three Stream Sites Across a Gradient of Watershed Urbanization in Southeastern Wisconsin Chosen as Fish and Macroinvertebrate Sampling Sites.

Subwatersheds ranged in size between 555 and 10,173 hectares (ha) with a mean size of 2,833 ha. Impervious surfaces in the subwatersheds ranged from 1.9 to 46.3 percent with a mean of 12.0 percent. One single stream site was chosen from which to sample in each subwatershed. All sampling sites were warmwater streams (summer maximum daily mean temperature exceeded 24°C), second to third order in size, and had low to moderate gradients (less than 6 m/km). These stream sites, in the absence of differing watershed land uses, were expected to have similar habitat and biological communities (Lyons, 1996).

Macroinvertebrate Sampling

In October 1997, aquatic macroinvertebrates were sampled from riffle and snag habitats separately at each stream site using a 600 μm mesh D-frame kick net. At sites where a riffle habitat was not available, a second snag habitat sample was collected. Riffles were defined as areas where water velocity was greatest (preferably 0.3 m/s or greater), and turbulent

surface water flows occurred due to a decrease in depth. Bottom substrates were composed of rubble, gravel, small rocks, or other stable habitat of fairly uniform sizes. Snags were defined as accumulations of vegetative debris including leaves, twigs, grasses, and aquatic macrophytes on branches, logs, or other objects within the stream channel. The snags were partially or fully submerged.

During sampling, each habitat was approached from downstream so that it was not disturbed before the D-frame net was put in place. At riffles, the D-frame net was positioned on the stream bottom and the substrate just upstream from the net was vigorously disturbed by kicking. This process dislodged macroinvertebrates, allowing them to be washed into the net (Hilsenhoff, 1987). At snags, the D-frame net was positioned in the water column where it would collect most of the dislodged debris. Depending on the water depth, the snag was slowly disturbed with hands or feet. If the net became clogged, it was cleared and the collection process was continued.

Three subsamples were collected at each habitat type. Riffles were sampled across a horizontal transect with subsamples taken in succession along the transect. If the stream was too narrow for three successive subsamples to be collected across the horizontal transect, samples were collected moving upstream. Snag subsamples were collected with first consideration given to the largest snags in areas with the highest water velocity. Additional snags were sampled with similar consideration given to size of snag and water velocity.

Subsamples were combined to ensure that at least 125 organisms with assigned biotic index (BI) tolerance values were obtained (Hilsenhoff, 1987). At highly degraded sites where macroinvertebrates or appropriate sampling habitats were rare, extensive sampling effort was required to obtain the minimum sample size. In such cases, regardless of the number of macroinvertebrates collected, sampling was stopped after one hour or after a standard fish and habitat sampling reach (35 times mean stream width) (Lyons, 1992) had been surveyed.

Large debris collected in the D-frame net was rinsed to obtain macroinvertebrates and then discarded at the site. All organisms found clinging to the net were removed and placed in sample collection jars. Samples were preserved in 80 percent isopropyl alcohol, and transferred to fresh alcohol after 24 and 48 hours. Samples were then transported to the laboratory for sorting and identification.

In the laboratory, macroinvertebrates and debris were placed in a Pyrex® plate positioned over a grid comprised of 6.5 cm^2 squares. A grid square was randomly chosen from which to remove organisms. With the aid of an illuminated magnifying lamp, all invertebrates were removed from the grid square and organisms that had BI tolerance values were enumerated. The process was repeated in additional, consecutively numbered grid squares until a minimum of 125 organisms with BI tolerance values had been enumerated or until the entire sample had been processed.

Macroinvertebrate taxa were identified to the lowest taxonomic level at which a BI tolerance value was defined (Hilsenhoff, 1987). Organisms without defined BI tolerance values were identified to the lowest level of taxonomic resolution possible. Chironomid larvae were slide mounted in CMC-10 mounting media (Master's Chemical Company, Inc., Bensenville, Illinois) to increase clarity of specimens, and were allowed to clear for two days before identification.

Watershed Landuse

Watershed landuse and percent impervious area were derived from a GIS database that was prepared and maintained by the Southeastern Wisconsin Regional Planning Commission. The database was developed from 1:4,800 scale aerial photos taken in 1990. Resolution of the database was about 0.40 ha. in rural areas and 0.06 ha. in urban areas. From this data-base, we selected seven urban land use categories including transportation, commercial, industrial, residential, government, recreational, all urban lands, and three nonurban land uses including agricultural, water/wetland, and open land.

Each subwatershed boundary upstream of the sampling sites was delineated by hand on 1:24,000 scale topographic maps using ARC/INFO software (ESRI, 1994). We quantified watershed landuse by overlaying watershed boundaries on top of the landuse database with ARC/INFO software. We expressed the area of each of the ten major landuse categories as a percent of each watershed's area.

In addition, we determined the percentage of the watershed as effective connected imperviousness as another urban landuse, defined as those areas which were impervious to infiltration by precipitation and which had direct hydraulic connection to the downstream drainage system (Booth and Jackson, 1997). The connected impervious area was calculated based on a previous study that had estimated typical levels of connected imperviousness for different types of urban land uses in southeastern Wisconsin (Personal Communication, R. T. Bannerman, Wisconsin Department of Natural Resources, Madison, Wisconsin).

Data Analyses

We calculated several measures of stream quality using macroinvertebrates to assess the impacts of urbanization on streams. These measures, termed metrics (Plafkin *et al.,* 1989), included both a biotic index (BI) (Hilsenhoff, 1987) and a diversity index (Shannon and Weaver, 1949). The BI is a widely used measure of the quality of macroinvertebrate communities and is an effective method to assess organic and nutrient pollution for stream ecosystems (Hilsenhoff, 1987). Its values range from 0 to 10, with lowest values indicating excellent stream quality and highest values representative of very poor stream quality. We also calculated generic and species richness (Gaufin, 1957), and percent of the pollution intolerant Ephemeroptera, Plecoptera, and Trichoptera (EPT) individuals to detect the influence of urbanization on sensitive macroinvertebrates. Finally, we calculated metrics that described functional feeding group composition, specifically, percent of collectors, filterers, gatherers, scrapers, and shredders (Merritt and Cummins, 1996). Collectors were a combination of the filterers and gatherers that feed on suspended particles in the water column or deposits on the substratum.

A preliminary analysis (SPSS, 1998) on ln transformed metric data indicated that the data from the two sampling habitats were significantly different; we analyzed the riffle and snag data separately in all our statistical procedures. We performed Pearson correlation analysis (SAS, 1992) to evaluate the correlation between the major land use categories, including percent of watershed imperviousness, and the stream quality metrics described by the macroinvertebrate community. We then identified a key urban landuse variable based on its correlation with macroinvertebrate community attributes and its representativeness of other urban variables. We analyzed the relationship between stream quality metrics and the key urban landuse variable by conducting regression analyses on ln transformed data (SPSS, 1998). Finally, we visually examined the relationships between stream quality metrics and the key urban landuse variable to identify at what level of urbanization macroinvertebrate community attributes showed dramatic change and at what level of urbanization the macroinvertebrate community attributes were consistently poor.

RESULTS

Among the 11 land use variables considered, urban land uses were positively correlated and nonurban land uses were negatively correlated with the Hilsenhoff biotic index, and percent collectors and percent gatherers for riffle samples (Table 1). These land uses were not correlated with percent collectors and gatherers for snag samples (Table 2). The urban land uses were negatively correlated and nonurban land uses were positively correlated with the Shannon diversity index, percent EPT individuals, generic richness, and percent of filterers and shredders for both riffle and snag samples. Percent scrapers showed a similar relation as filterers with the land uses, but only for riffle samples; scrapers were only correlated with government landuse for snag samples.

The correlation coefficients between the 11 landuse variables and macroinvertebrate community attributes varied considerably between the two habitat types and among the regression pairs (Tables 1 and 2). Among the urban landuse variables, percentages of watershed imperviousness, commercial, and government land uses, and transportation had the highest correlation coefficients and were significantly correlated with all the macroinvertebrate community attributes for riffle habitat. For snag habitat, these same landuse categories were also most highly correlated, but were correlated with fewer total macroinvertebrate community attributes. Percentages of industrial and residential land uses had the lowest correlation coefficients and correlated with the least number of macroinvertebrate attributes. Among the nonurban land uses, woodland and water/wetland were generally correlated with macroinvertebrate community attributes more strongly than was agricultural land use. Because percentages of watershed imperviousness well represented the relation between urban land uses and macroinvertebrate community attributes for both riffles and snags, and because imperviousness was highly correlated with the other urban landuse variables ($r = 0.47$ to 0.98, $p \leq 0.01$), we chose percent imperviousness to represent urban land uses to examine the impacts of urbanization on macroinvertebrate communities.

A significant, although weak, nonlinear relationship existed between the BI and percent watershed imperviousness ($p < 0.01$; Figure 2). BI values ranged from 3.8 to 8.1 for riffle sites and from 3.8 to 9.8 for snag sites, indicating a range of very good to very poor stream quality (Figure 2). For both habitats, the BI increased sharply when imperviousness was between 8 and 12 percent, and it showed less dramatic increases once watershed imperviousness exceeded about 12 percent. For watersheds with imperviousness less than 12 percent, which corresponded to areas of relatively high agricultural use, BI values were highly variable (Figure 2). Some sites had very good stream quality (BI range: 3.8 to 4.5), while others had poor or very poor stream quality (BI range:

TABLE 1. Pearson Correlation Coefficients Between Macroinvertebrate Community Attributes at Riffles (all variables were ln-transformed) and Watershed Land Cover Variables (percent of watershed). Coefficients are listed only for regression slopes that were significant at $p \leq 0.05$ (*) and at $p \leq 0.01$ (**).

Land Cover Variables (percent)	BI	Shannon Diversity	EPT Individuals (percent)	Generic Richness	Filterers (percent)	Scrapers (percent)	Shredders (percent)	Collectors (percent)	Gatherers (percent)
Urban Land Uses									
Imperviousness	0.50**	-0.56**	-0.38*	-0.39*	-0.37*	-0.63**	-0.40*	0.58**	0.50**
Transportation	0.49**	-0.52**	-0.38*	-0.38**	-0.36*	-0.62**	-0.41*	0.58**	0.50**
Commercial Land	0.54**	-0.52**	-0.42*	-0.36*	-0.44**	-0.54**	-0.34*	0.50**	0.51**
Industrial Land									
Residential Land		-0.39*				-0.53**		0.54**	
Government Land	0.53**	-0.66**	-0.42*	-0.46**	-0.38**	-0.68*	-0.38*	0.58**	0.45**
Recreational Land		-0.43**	-0.30*			-0.39*		0.34*	
All Urban Lands	0.40*	-0.47**		-0.35*		-0.60**		0.58**	0.37*
Nonurban Land Uses									
Agricultural Land		0.42*		0.39*		0.53**	0.31*	-0.38*	-0.37*
Water/Wetland	-0.48**	0.68**	0.56**	0.42*	0.53**	0.62**	0.45**	-0.42*	-0.47**
Woodland	-0.56**	0.43**	0.41*			0.60**	0.40*	-0.55**	-0.49**

TABLE 2. Pearson Correlation Coefficients Between Macroinvertebrate Community Attributes at Snags (all variables were ln-transformed) and Watershed Land Cover Variables (percent of watershed). Coefficients are listed only for regression slopes that were significant at $p \leq 0.05$ (*) and at $p \leq 0.01$ (**).

Land Cover Variables (percent)	BI	Shannon Diversity	EPT Individuals (percent)	Generic Richness	Filterers (percent)	Scrapers (percent)	Shredders (percent)	Collectors (percent)	Gatherers (percent)
Urban Land Uses									
Imperviousness	0.53**	-0.33*	-0.46**						
Transportation	0.47**	-0.29*	-0.44**						
Commercial Land	0.49**	-0.32*	-0.37**		-0.29*				
Industrial Land	0.34*								
Residential Land	0.44**								
Government Land	0.46**	-0.42**	-0.41**	-0.29*		-0.31*			
Recreational Land	0.38**	-0.31*							
All Urban Lands	0.52 **		-0.35*						
Nonurban Land Uses									
Agricultural Land	-0.35*	0.38**	0.33*						
Water/Wetland		0.39**	0.53**	0.32*	0.36*		0.36*		
Woodland	-0.42**	0.37**	0.51**		0.29*		0.32*		

7.5 to 9.8). Watersheds with imperviousness greater than 12 percent had fairly poor to poor stream quality (BI > 7.5), with the exception of three riffle sites.

Significant, but weak nonlinear negative relationships were found between the Shannon diversity index, percent EPT individuals and generic richness, and percent of watershed imperviousness ($p \leq 0.05$; Figure 3). Similar to BI values, generic richness and Shannon diversity were more variable in watersheds with less than 12 percent imperviousness. For both metrics, data were less variable in riffle habitats, producing a stronger model fit at riffles than snags. Although the relationship between imperviousness and percent EPT individuals were similar to those with other stream quality metrics, EPT compositions were consistently low only when watershed

imperviousness was greater than 20 percent at both snag and riffle samples.

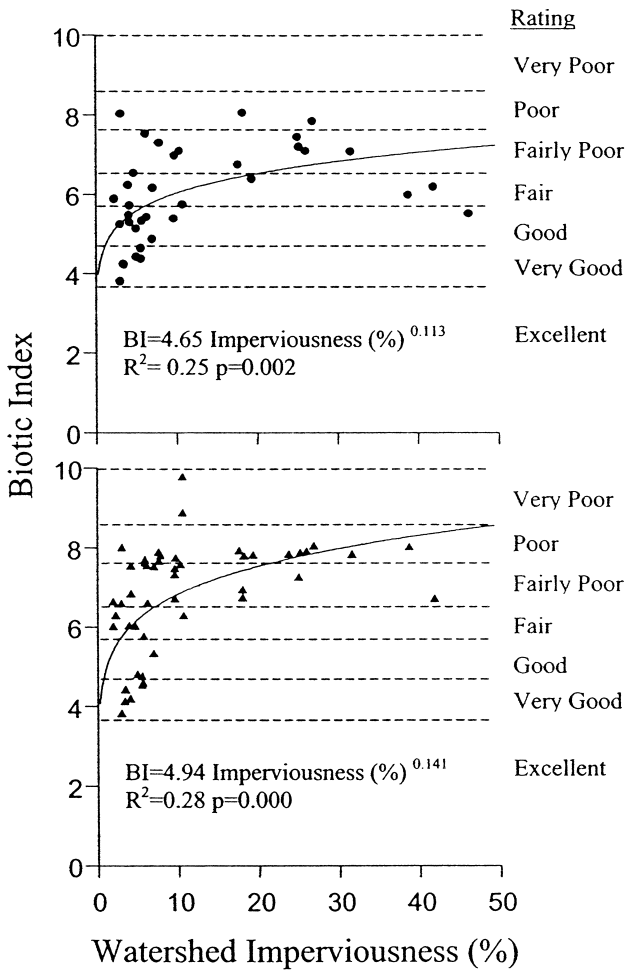

Figure 2. Plot of Relationship Between Biotic Index (BI) and Watershed Imperviousness (percent) at Riffle and Snag Habitats in 43 Southwestern Wisconsin Streams. Stream quality ratings are from Hilsenhoff (1987). Riffles are represented by circles in the upper plot, while snags are represented by triangles in the lower plot.

Functional feeding group composition was often altered with increased watershed imperviousness. Nonlinear negative relationships were found between percent filterers and shredders and watershed imperviousness at both snag and riffle habitats ($p = 0.02$-0.07; Figure 4). The strongest overall relationship observed in our study was the negative nonlinear relationship between percent scrapers and watershed imperviousness at riffles ($r^2 = 0.40$; Figure 5). Conversely, percent gatherers and collectors showed positive relationships with watershed urbanization at riffles (Figure 5). There were no significant relationships between percent scrapers, collectors, and gatherers, and watershed imperviousness for snag samples (Table 2).

DISCUSSION

Landuse Effects on Macroinvertebrates

Our results demonstrated that watershed land uses had significant impacts on stream macroinvertebrate communities. These impacts included negative effects of urban land uses and positive effects of nonurban land uses on the Hilsenhoff biotic index, Shannon diversity index, the composition of the pollution intolerant Ephemeroptera, Plecoptera and Trichoptera, and generic richness across the gradient of watershed imperviousness. These findings were consistent with other studies that considered impacts of urbanization on macroinvertebrates (e.g., Lenat and Crawford, 1994; Shaver *et al.,* 1995; Horner *et al.,* 1996), fish (e.g., Steedman, 1988; Schueler, 1994; Weaver and Garman, 1994; Wang *et al.,* 1997; Wang *et al.,* 2000; Wang *et al.,* 2001) and both macroinvertebrates and fish (e.g., Klein, 1979; May *et al.,* 1997).

The positive relations between agricultural land use and stream quality metrics are contrary to other studies on the effects of agriculture on stream ecosystems. For example, in analysis of 213 headwater streams in southern Ontario, Barton (1996) found that macroinvertebrate taxa were significantly lower in agriculture dominated watersheds than those in reference watersheds. In comparing silvicultural, agricultural, and wilderness watersheds, Rothrock *et al.* (1998) reported that the two agriculture dominated watersheds had the most impoverished macroinvertebrate communities. Many studies have also shown negative relations between agricultural landuse and fish communities (e.g., Richards and Host, 1994; Roth *et al.,* 1996; Wang *et al.,* 1997; Wichert and Rapport, 1998). However, the key difference between our study and previous studies was that we contrasted agricultural land use with urban land use, whereas earlier studies contrasted agricultural land use with more natural land uses, typically forest. Certainly our results should not be interpreted as meaning that increased agricultural land use of a watershed is beneficial to a stream macroinvertebrate community. Rather, an inverse relationship existed between urban and agricultural land use in our study. This result indicated that urban land uses were generally more deleterious to stream macroinvertebrates than agricultural land uses, which was consistent with findings for fish communities on the same streams (Wang *et al.,* 2000).

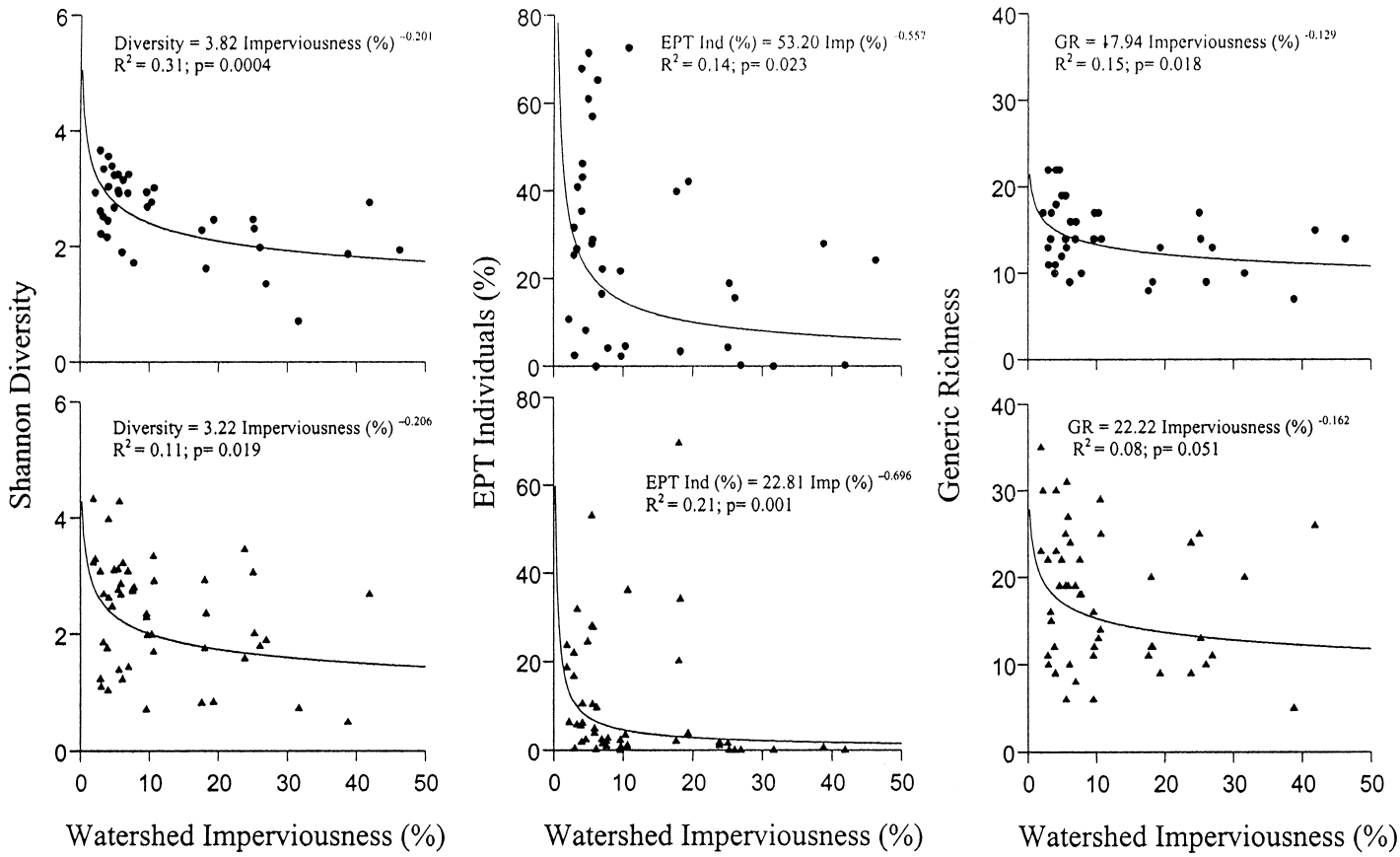

Figure 3. Plots of Relationships Between Shannon Diversity Index, EPT Individuals (percent), Generic Richness (GR), and Watershed Imperviousness (percent) at Riffle and Snag Habitats in 43 Southeastern Wisconsin Streams. Riffles are represented by circles in the upper plot, while snags are represented by triangles in the lower plot

Our results suggested that watershed connected imperviousness was an effective representative variable for measuring the effects of urbanization effects on stream macroinvertebrate communities in southeastern Wisconsin. Imperviousness is easily quantifiable by watershed planners and developers, and can be directly related to surface runoff. Profound impacts of imperviousness on stream hydrology and channel morphology have been well documented (Booth and Jackson, 1997). The process of urbanization, including clearing vegetation, compacting soil, ditching and draining, and constructing impervious roads and roofs produces changes in both the type and magnitude of runoff. A direct result of changes in surface runoff is modified stream discharge regimes, which result in excessive bank erosion, altered channel morphology and degraded aquatic habitat. Impervious surfaces also readily accumulate pollutants from many sources in urban areas, which may then be washed into streams with stormwater runoff. Stormwater runoff has been reported to be responsible for increased mortality of zooplankton and fish in field exposures (Crunkilton *et al.,* 1996) and elevated concentrations of pollutants in sediment and tissues of fish and crayfish (Masterson and Bannerman, 1994).

Imperviousness, Biotic Integrity and Diversity Relations

Similar trends between biotic integrity and diversity with imperviousness have been found in other studies with fish and macroinvertebrates, clearly demonstrating that biological communities can be degraded at relatively low levels of urban landuse. In a companion study of the same Wisconsin stream sites, Wang *et al.* (2000) found that both biotic integrity and diversity of fish communities were consistently low in watersheds with greater than 10 percent imperviousness. In the northern Piedmont region of Delaware, macroinvertebrate richness, composition, and tolerance measures declined at a level of imperviousness between 8 and 15 percent (Shaver *et al.,* 1995). Diversity of both fish and insect taxa declined

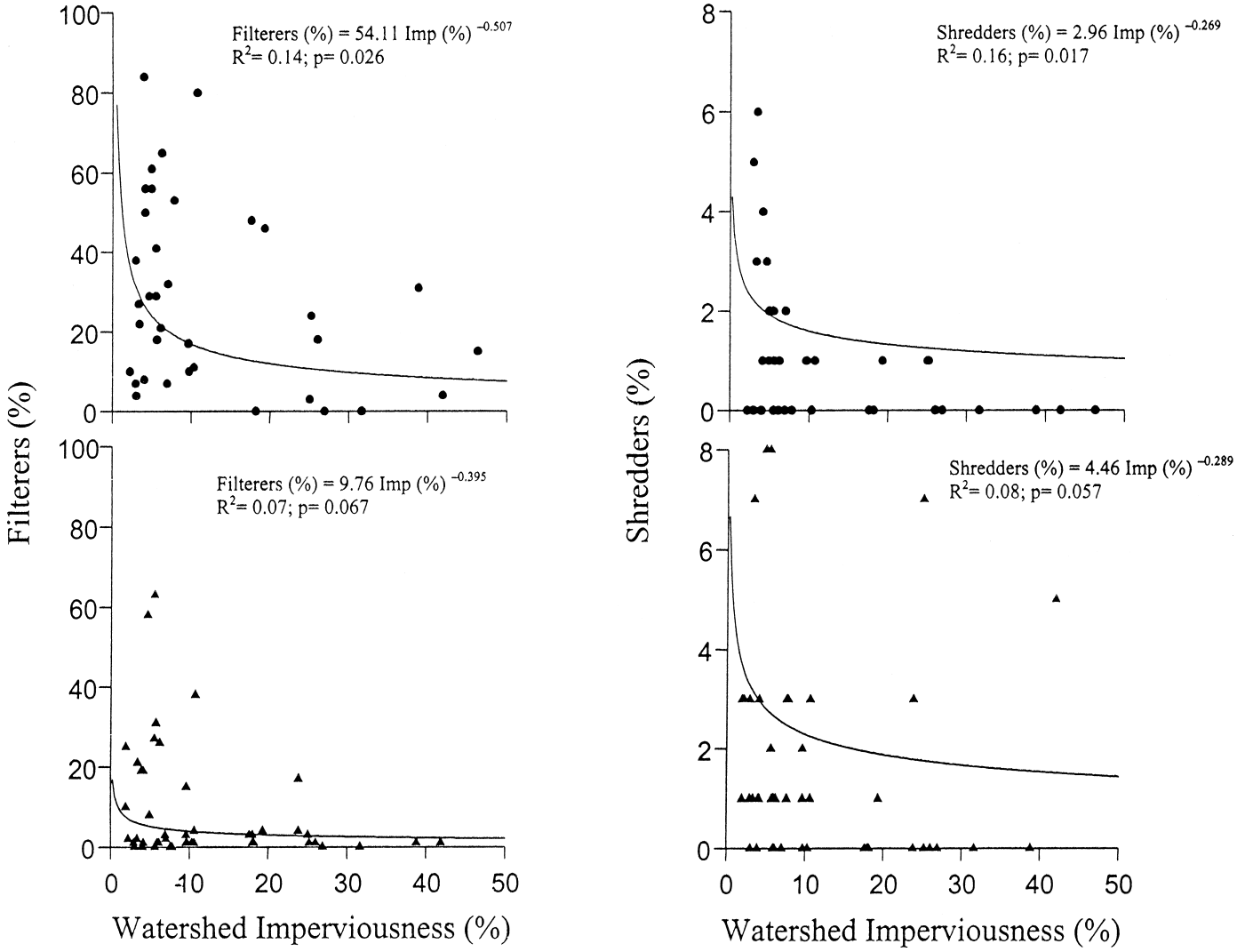

Figure 4. Plots of Relationships Between Filterers (percent), shredders (percent), and Watershed Imperviousness (percent) at Riffle and Snag Habitats in 43 Southeastern Wisconsin Streams. Riffles are represented by circles in the upper plot, while snags are represented by triangles in the lower plot.

from good to poor in Maryland watersheds with greater than 15 percent watershed imperviousness (Schueler and Galli, 1992). Benke *et al.* (1981) found that the number and diversity of macroinvertebrate species and families were negatively correlated with percent of urbanization for 21 streams near Atlanta, Georgia. Several studies on stream hydrology, channel morphology, and fish also showed that watersheds with more than 10 percent imperviousness had consistently high discharge fluctuations, increased bank and channel erosion, and poor biotic richness and integrity (e.g., Duda *et al.,* 1982; Pitt and Bozeman, 1983; Garie and McIntosh, 1986; Pederson and Perkins, 1986; Lenat and Crawford, 1994; Schueler, 1994; Booth and Jackson, 1997; May *et al.,* 1997; Wang *et al.,* 1997; Wang *et al.,* 2000).

Almost all the data scatter diagrams for macroinvertebrate attributes and imperviousness had a similar visual relationship. Sites in highly impervious watersheds were always associated with low metric values, but both high and low metric values were recorded at sites in watersheds with low percents of imperviousness. The relatively low correlation coefficients reported here between measures of imperviousness and macroinvertebrate community attributes can be attributed to the variation at low percent imperviousness. In examining the same set of streams, Wang *et al.* (2001) reported similar visual relations, which they termed "wedge-shaped," between imperviousness and fish community measures. They concluded that such relations were found mainly in areas where rural land uses were

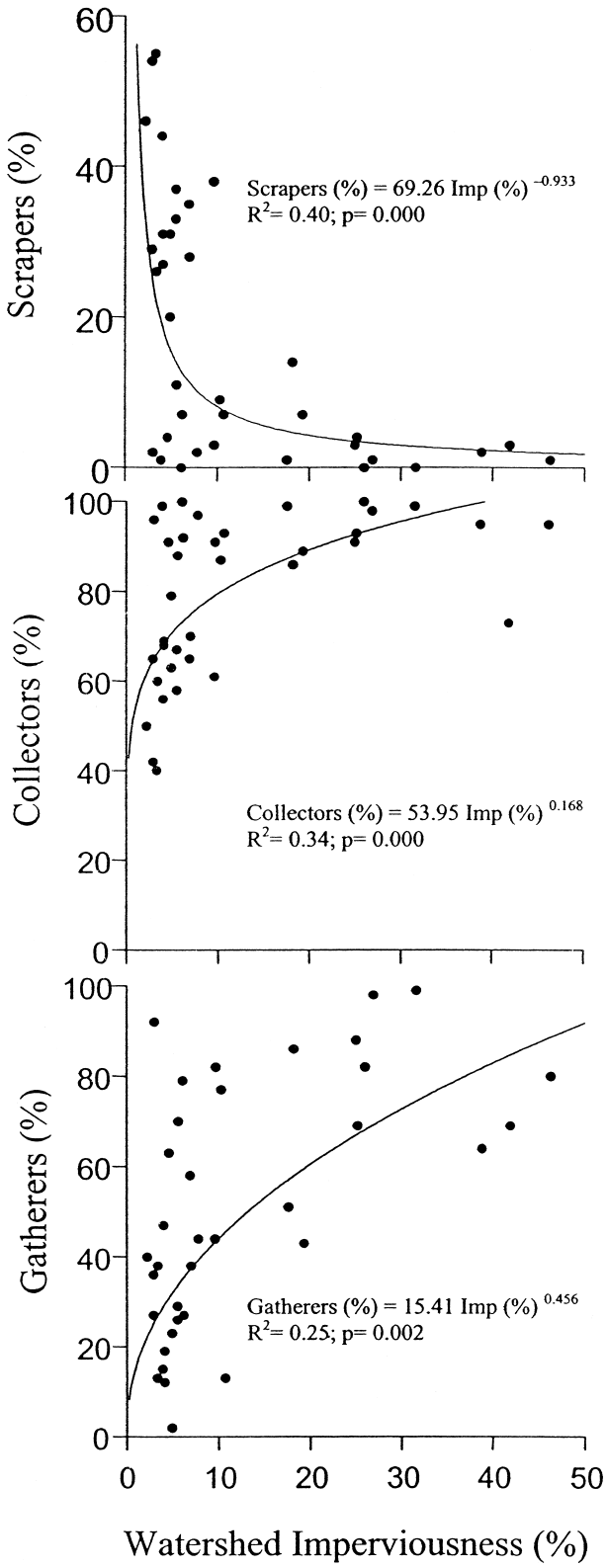

Figure 5. Plot of Relationship Between Scrapers (percent), Collectors (percent), Gatherers (percent), and Watershed Imperviousness (percent) at Riffle Habitat in 43 Southeastern Wisconsin Streams.

dominated by agriculture and low metric values, whereas linear relations were found in areas where rural landscapes were less modified and remained mainly forest yielding high metric values. Wang *et al.* (2001) reported that quantile regression can better identify the upper and lower bound slopes of dependent variables from data sets represented by wedge-shaped distributions than the least square procedure used here.

Imperviousness and Biotic Feeding Group Relations

The decline in percent scrapers at riffle sites suggested that the pollution tolerance of the scrapers was related to food source availability and suitability. Light, nutrients, and temperature regimes may have been altered at sites with higher levels of imperviousness, thus altering production and species of periphyton, the preferred food source of scrapers (Cummins, 1976). The type of periphyton (i.e., filamentous algae) at the highly impervious watershed sites may not have been suitable for scrapers (Cummins, 1992). The increase in collectors and gatherers with greater imperviousness suggests availability of more fine particulate food resources in the water column or on the stream substrate in these areas.

CONCLUSIONS

Our study clearly demonstrated that urbanization significantly degraded stream macroinvertebrate communities, hence stream quality. Our results confirmed that the amount of connected impervious surface in a watershed was a useful indicator of impacts of urban landuse on stream macroinvertebrate communities. Using imperviousness as a measure of urbanization, we developed relationships between levels of urbanization and stream quality metrics. Good stream quality, as indicated by desirable values of the Hilsenhoff biotic index, Shannon diversity, and pollution intolerant individuals appeared likely if watershed imperviousness was less than 8 percent. Levels of watershed imperviousness between 8 and 12 percent seemed to represent a threshold where minor increases in urbanization were associated with sharp declines in macroinvertebrate communities.

ACKNOWLEDGMENTS

We thank John Lyons and Paul Kanehl for the study design and field data collection; Roger Bannerman, Robert Beabal, and John McDougall for preparing watershed land use data; Tom Aartila, Mary Botzet, Kevin Fassbind, Scott Harpold, and Mike Miller for their help collecting macroinvertebrates; and Sarah Sonsthagen, Sunshine Kapusta, Chris Huff, Pat Short, Kathy Smikrud, Bruce Medhurst, Marty Torpy, and Jenni Stritzel for their assistance with macroinvertebrate sorting. We are grateful to Jeff Dimick for his aid with macroinvertebrate identification, instruction in lab techniques, and editorial comments on this manuscript; Mike Hansen for his assistance with nonlinear modeling; and Stan Szczytko and Chris Hartleb for their editorial comments on this manuscript. This project was funded by the Wisconsin Department of Natural Resources through a contract with the Bureau of Watershed Management and the College of Natural Resources at the University of Wisconsin-Stevens Point.

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